# ESTIMATION OF TEMPERATURE DISTRIBUTION INSIDE BIOLOGICAL TISSUES BY MEANS OF MULTIFREQUENCY MICROWAVE THERMOGRAPH

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*Abstract* - **This paper presents problems connected with thermal radiation of human bodies in microwave range in aspect of diagnosis breast carcinoma. A mathematical model of transmission thermal radiation through tissues is introduced and methods of measurement of temperature, depth and size of heat source, by means of multifrequency microwave thermograph, are described. Theoretical considerations are supplemented by presentation of results of experiments.**

***Keywords*** **- microwave thermograph, radiometer, thermal radiation, breast carcinoma.**

## I. INTRODUCTION

The passive microwave thermography is based on measurement of thermal radiation emitted by each body, which has the temperature higher than the absolute zero. The greatest intensity of radiation is in the infrared, but high attenuation of tissue in this range limits application of the infrared thermography only to measurements of skin temperature. In the microwaves the intensity of radiation is about ten million times less but attenuation of tissue is low. Moreover in this range the intensity of radiation is directly proportional to the temperature on the absolute scale.

Thermal radiation going out from a biological body is attenuated in each layer of tissue. Moreover it is reflected and at the same time refracted on the interfaces of different layers. The initial analysis indicates that attenuation, characterised by depth of penetration, is the most important.

Analysis of characteristics of radiation and attenuation makes it possible to conclude, that measurements on several frequencies will enable us to estimate the depth and the size of the heat source. For anatomical depths of the heat source the computer simulation shows that the maximum of intensity of the received radiation is in the range between 1 and 5GHz. So, we use radiometers working in this range.

The monofrequency radiometry enables measurement of average temperature of a certain area. So, we don't know whether the heat source is cool and not deep under the skin or perhaps it is hot but deeply situated. In both cases the temperature brightness on the external surface may be equal. We only know that there is an area of increased temperature under the antenna, which may indicate the presence of tumour.

From the practical point of view the problem of estimation of spatial temperature distribution inside the investigated object is particularly interesting. The presented solution uses the power thermography on different frequencies [1÷4]. This method is based on the increasing intensity of thermal radiation and at the same time on the decreasing depth of penetration into biological tissues vs. frequency.

As presented in [4] the three-layer model of tissue increase of the physical temperature of the internal heat source $T$ is connected with increase of the effective temperature brightness $T_f$ on the external surface of tissue, measured by a radiometer working on frequencies $f$, and is expressed by the following formula

$$T_f = T \exp\left(-\frac{d_g}{\delta_g}\right) t_{gf} \exp\left(-\frac{d_f}{\delta_f}\right) t_{fs} \cdot \cdot \exp\left(-\frac{d_s}{\delta_s}\right) \cdot \left(1 - \left|\Gamma_f\right|^2\right) \quad (1)$$

where: $d_g$, $d_f$, $d_s$ – lengths of ways in layers of gland, fat and skin,
$\delta_g$, $\delta_f$, $\delta_s$ – power penetration distance in each layer,
$t_{gf}$, $t_{fs}$ – coefficients of power transmission on the interfaces contact,
$\Gamma_f$ – reflection coefficient on antenna and skin interface.

## II. THREE – BAND MICROWAVE RADIOMETER SYSTEM

From the structure of tissue and properties of a tumour, one can conclude that cancer has a spherical shape and the distribution of temperature originating from it exponentially decreases to 0 in the layer of gland. So, the Gauss curve has been assumed as the function, which describes deep–seated temperature distribution –

$$T(z) = T_S \exp\left[-\left(\frac{z - d_g}{\sigma}\right)^2\right] \quad (2)$$

This is illustrated in fig. 1.

In this situation, increase of the maximum physical temperature of the internal heat source $T_S$ is connected with increase of the temperature brightness (1) on the external surface $T_f$, and is expressed by the following equation

$$T_f = T_g t_{gf} \exp\left(-\frac{d_f}{\delta_f}\right) t_{fs} \exp\left(-\frac{d_s}{\delta_s}\right)\left(1 - \left|\Gamma_f\right|^2\right) \quad (3)$$

In this equation $Tg$ is the effective temperature on the gland and fat interface and it is defined with an integral of temperature distribution $T(z)$ in range from zero to infinity, with regard of transfer coefficient –

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**Abstract**

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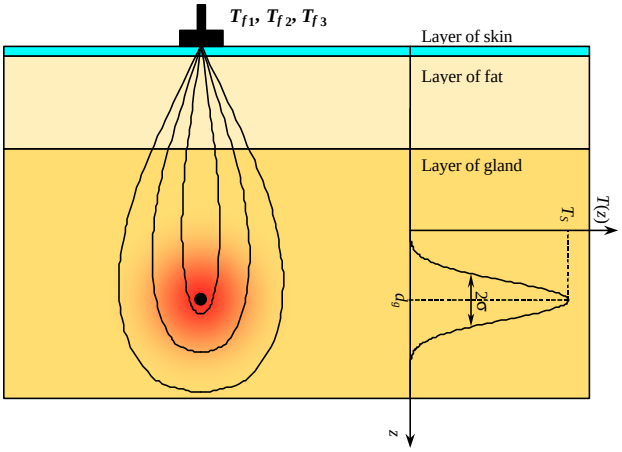


Fig. 1. Distribution of temperature inside biological tissue

$$\xi(z) = \exp\left(-\frac{z}{\delta_g}\right) \tag{4}$$

From (2) and (4) we obtain

$$T(\xi) = T_S e^{-\left(\frac{d_g}{\sigma}\right)^2} \xi^{-\frac{\delta_g}{\sigma^2}\left(\delta_g \ln \xi + 2d_g\right)} \tag{5}$$

Integrating in relation to $z$ from zero to infinity is equivalent to integrating in relation to $\xi$ in a range <0, 1> and consequently, for

$$d_g \le d_{g\min} = 2\sigma + \frac{\sigma^2}{2\delta_g} \tag{6}$$

the effective temperature of noise on border of gland and fat is defined

$$T_g = \int_0^1 T(\xi)\,\mathrm{d}\xi = \frac{T_S \sigma\sqrt{\pi}}{\delta_g} \exp\left(\frac{\sigma^2 - 4\delta_g d_g}{4\delta_g^2}\right) \tag{7}$$

Because layer of skin in tested place, taking into account its slender thickness, one can treat it as a thin layer and in radiometers constructed in *Military University of Technology* in Warsaw $\Gamma_f = 0$ [5], dependence (3) accepts form

$$T_f = \frac{T_S \sigma\sqrt{\pi}}{\delta_g} \exp\left(\frac{\sigma^2 - 4\delta_g d_g}{4\delta_g^2}\right) K_f \tag{8}$$

where

$$K_f = t_{gf} \exp\left(-\frac{d_f}{\delta_f}\right) \tag{9}$$

As a result of the calibration process we obtain coefficients $K_f$ for three radiometers working on different frequencies. Using these coefficients and the proper depths of penetration we can estimate the real temperature distribution by means of multifrequency measurement. By solving the set consisting of this equation for three frequencies: $f_1$, $f_2$, $f_3$ we obtain expressions describing the real temperature distribution inside investigated tissue:

$$\begin{aligned} d_g &= \frac{\alpha\cdot\delta_{g1}^2\left(\delta_{g2}^2 - \delta_{g3}^2\right) - \beta\cdot\delta_{g3}^2\left(\delta_{g1}^2 - \delta_{g2}^2\right)}{\delta_{g1}^2\left(\delta_{g2} - \delta_{g3}\right) - \delta_{g2}^2\left(\delta_{g1} - \delta_{g3}\right) + \delta_{g3}^2\left(\delta_{g1} - \delta_{g2}\right)} \\ \sigma &= 2\delta_{g1}\delta_{g2}\sqrt{\frac{d_g\left(\delta_{g2}^{-1} - \delta_{g1}^{-1}\right) - \alpha}{\delta_{g1}^2 - \delta_{g2}^2}} \\ T_s &= \frac{T_{f1}\delta_{g1}}{\sigma K_{f1}\sqrt{\pi}} \exp\left(\frac{4\delta_{g1}d_g - \sigma^2}{4\delta_{g1}^2}\right) \end{aligned} \tag{10}$$

where:

$$\alpha = \ln\left(\frac{T_{f1}\cdot K_{f2}\cdot\delta_{g1}}{T_{f2}\cdot K_{f1}\cdot\delta_{g2}}\right), \qquad \beta = \ln\left(\frac{T_{f2}\cdot K_{f3}\cdot\delta_{g2}}{T_{f3}\cdot K_{f2}\cdot\delta_{g3}}\right)$$

Complete depth of the heat source is increased by width of fat and skin layers:

$$d = d_g + d_f + d_s \tag{11}$$

## III. Temperature Measurement Experiments

For verification of this method, we used the measuring position presented in the fig. 2. As the tissue, we used the beef meet. As the heat source, we used the polypropylene tube of diameter 5 mm, containing 1.5% saline solution.

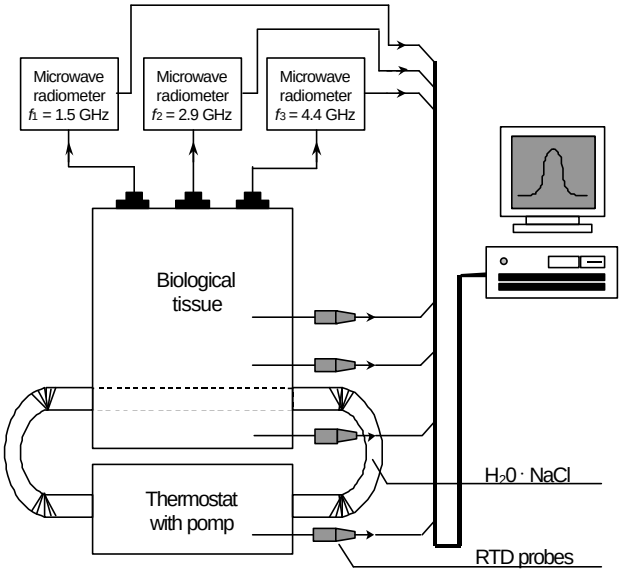


Fig. 2. Measuring position

The temperature of saline was regulated by the thermostat. To inspect the physical temperature distribution inside the tissue we used mini hypodermic probes with platinum RTD element. In the range of temperatures from 30°C to 45°C, conductivity of the solution is about 2S/m, and relative permittivity falls into a range from 70 to 75. Such parameters assure very good coefficient of power transmission on the solution and tissue interface. In measuring range of frequency, it is equal 0.99. Side of tube can be omitted in analysis because its thickness is equal 0.1mm.

To test the noninvasive thermometry based on the principles described in this paper, we used the experimental three–band radiometer system, which measured the temperature brightness at 1.5GHz, 2.9GHz and 4.4GHz. Measurements were made automatically and the results were displayed and stored by means of PC.

Experiment has been realised for two widths of layer the muscle with use of wide distribution of temperature. Distribution should be sufficiently wide in relation to dimensions of tube, so that its influence on results was prevailing, and at the same time not too wide for the sake of condition (6).

Fig. 3 and 4 show results of measurements and theoretical characteristics. Theoretical calculations are shown as lines and the results of measurements are shown as points.

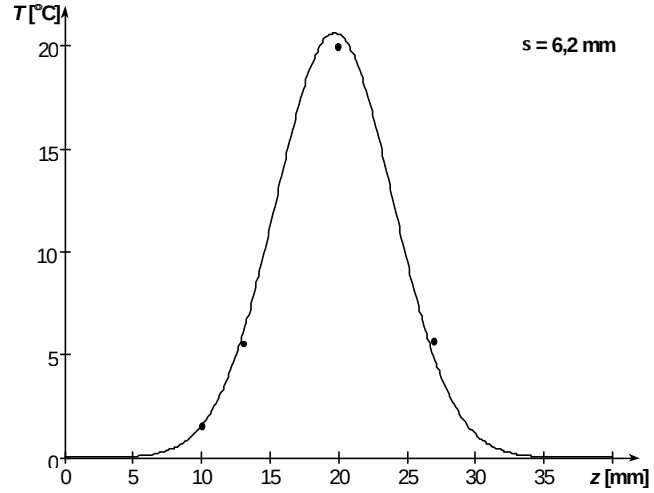


Fig. 3. Results of measurements for $d_g$ = 20mm and $T_S$ = 20°C

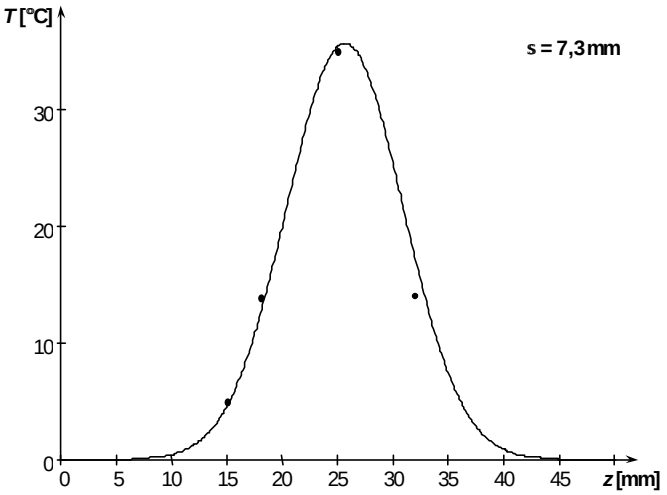


Fig. 4. Results of measurements for $d_g$ = 25mm and $T_S$ = 35°C

From these charts, we can conclude that the correctness of the presented analysis has been confirmed by this experiment. The obtained results indicate a possibility of noninvasive detecting and measuring of spatial temperature distribution inside a human body by means of multifrequency microwave thermograph [1÷4]. We hope that the method presented here will be used in oncology and other fields of medicine.

## IV. Conclusion

The aim of the work was elaboration of a measurement method permitting to construct a spatial microwave thermograph. This paper presents problems connected with thermal radiation of human bodies in microwave range and description of transmission proprieties of living tissues.

The idea of spatial microwave thermography, resulting from theoretical analysis and results of experiments, is described in the paper. The theoretical analysis and experiments confirmed initial expectations, which has formed a base to an attempt of estimation of spatial temperature distribution inside biological tissues. At present, most promising is a construction of a thermograph as a multichannel receiver, with each channel being separate radio receiver. Also, delivery of signal simultaneously to all channels by one wide-band antenna would be advisable. In practice, however, the above postulate is difficult to realise.

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